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WHITE-FRINGED BEETLES
DISTRIBUTION, SURVEY, AND CONTROL

By C. F. Henderson and L. J. Padget
Division of Domestic Plant Quarantines

United States Department of Agriculture
Agricultural Research Administration
Bureau of Entomology and Plant Quarantine

Information for this circular has been drawn from life-history studies made by the Division of Cereal and Forage Insect Investigations; data on the South American distribution of white-fringed beetles collected by the Division of Foreign Parasite Introduction; treatment methods worked out by the Division of Control Investigations; taxonomic determinations made by the Division of Insect Identification; and information on domestic distribution, survey, and control assembled by the Division of Domestic Plant Quarantines.

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A race of white-fringed beetles, Graphognathus leucoloma fecundus (Buch.), was first reported in the United States in September 1936, when adult specimens submitted by A. N. Tissot of the Florida Agricultural Experiment Station were identified in the Bureau's Division of Insect Identification. Later in that year the beetles were found in northwest Okaloosa County, Fla., where they were causing appreciable injury to peanuts. Beetles also were found in northern Walton County, Fla., and in contiguous areas in Covington and Geneva Counties, Ala. The first investigations on the economic importance of white-fringed beetles were made in May 1937, by J. R. Watson of the Florida Agricultural Experiment Station and U. C. Loftin of the Bureau of Entomology and Plant Quarantine. These studies indicated that the larvae were causing appreciable damage to cotton, corn, peanuts, velvetbeans, and other crops grown in the areas mentioned. Other closely related species and races of Graphognathus were subsequently found also causing economic damage, and all are collectively referred to as white-fringed beetles.

Subsequent to these preliminary investigations, delegations of entomologists and insect pest control officials from a number of widely separated States then visited the infested area, and as a result of their studies and observations they concluded that white-fringed beetles were a serious threat to a wide range of cultivated crops grown in many of the agricultural areas of the United States.

In July 1937 the Bureau of Entomology and Plant Quarantine, the State Plant Board of Florida, and the Alabama Department of Agriculture and Industries determined that a cooperative white-fringed beetle control project should be established immediately. This work was organized under the supervision of the Division of Domestic Plant Quarantines in the Bureau of Entomology and Plant Quarantine. The purposes of this project were to reduce populations by the application of suitable control measures and to prevent further spread by effective quarantine action. In the same year a research project in the Division of Cereal and Forage Insect Investigations was established to study the biology of the beetles and obtain other pertinent information necessary for controlling these insects and preventing their further spread.

ECONOMIC IMPORTANCE

White-fringed beetles cause serious damage to many field crops of economic importance in the Southern States (figs. 1 and 2). Most of the damage is done by the larvae, which feed on the roots of practically any

Figure 3.--Larvae.

Figure 4.--Pupa in soil cell.

Figure 5.--Adult.

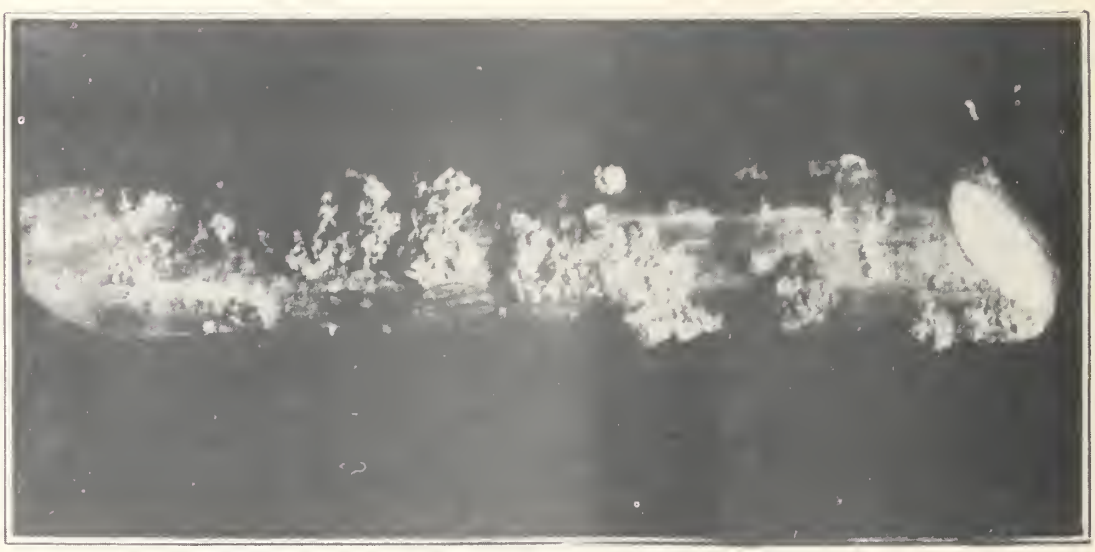

Figure 6.--Egg masses cemented to twig.

Stages of the White-fringed Beetle Graphognathus leucoloma fecundus.

insect would impose a hazard on agriculture and levy a heavy toll on the production of susceptible crops.

DESCRIPTION

White-fringed beetle larvae are approximately one-half inch long when full-grown, strongly convex, yellowish white, legless, and typically weevil in form (fig. 3). The head is slightly darker and partially retracted into the body. It bears two stout black mandibles, which it uses in feeding on the roots of plants.

The pupae are approximately seven-sixteenths of an inch in length and are immobile except for the abdomen (fig. 4).

Adult beetles are approximately seven-sixteenths of an inch in length and about five thirty-seconds of an inch across the abdomen, brownish gray in color, with a lighter band along the margins of the wing covers (fig. 5). The common name of the insect is based on this lighter band. Two paler longitudinal lines also occur on each side of the thorax and head, one above and one below the eyes. The body is densely covered with very short hairs; those on the wing covers are somewhat longer. The snout is short and stout and bears clubbed antennae. The underwings are rudimentary, and the basal margins of the wing covers are fused to the mesonotum. The beetle is thus unable to fly.

The eggs are oval in shape and a little more than one thirty-second of an inch in length. They are milky white when freshly deposited but turn to a dull light yellow after 4 or 5 days (fig. 6).

LIFE HISTORY

Larvae are usually found in the upper 9 inches of soil, where they are in contact with or close to the roots of food plants. They are nearest the surface during March and April. At maturity the larvae go through a short inactive stage and then form cells in the soil, where they remain quiescent for several days longer before transforming into pupae. Pupation generally occurs during May, June, or July, the time varying with locality and climate. However, some nonfeeders remain in the soil for a year or more as carry-over larvae. The pupal stage is of 8 to 15 days' duration, after which the skin is molted and the young adult remains in the pupal cell for several days, enabling the body wall to harden. Adult beetles begin to emerge early in May and continue to emerge until mid-August, the time depending upon species, locality, and climate. Emergence from the ground usually takes place after a rain. The beetles feed on leaf tissue for several days and then begin oviposition.

Eggs are deposited in masses of 15 to 25 cemented to sticks, debris, or soil, and are partially concealed by fine particles of soil. They hatch in approximately 2 weeks during warm weather when sufficient moisture is present. Eggs have been kept viable for more than 7 months when

held in a dry condition. The total number of eggs deposited is dependent upon the food plants on which the adult feeds. Beetles feeding on grass deposit only a few eggs (from 15 to 60), whereas leguminous plants such as peanuts and velvetbeans are conducive to heavy oviposition (1,500 or higher). Adults live for 2 or 3 months, and egg laying continues intermittently throughout most of this period. The insects pass the winter in the soil as small to half-grown larvae, except for the few full-grown carry-over larvae as described above. The life cycle is shown in figure 7.

White-fringed beetles are parthenogenetic. No males are known, and every adult is a female capable of producing viable eggs. A single beetle, therefore, or any egg or larvae may establish a new infestation wherever environmental conditions are favorable.

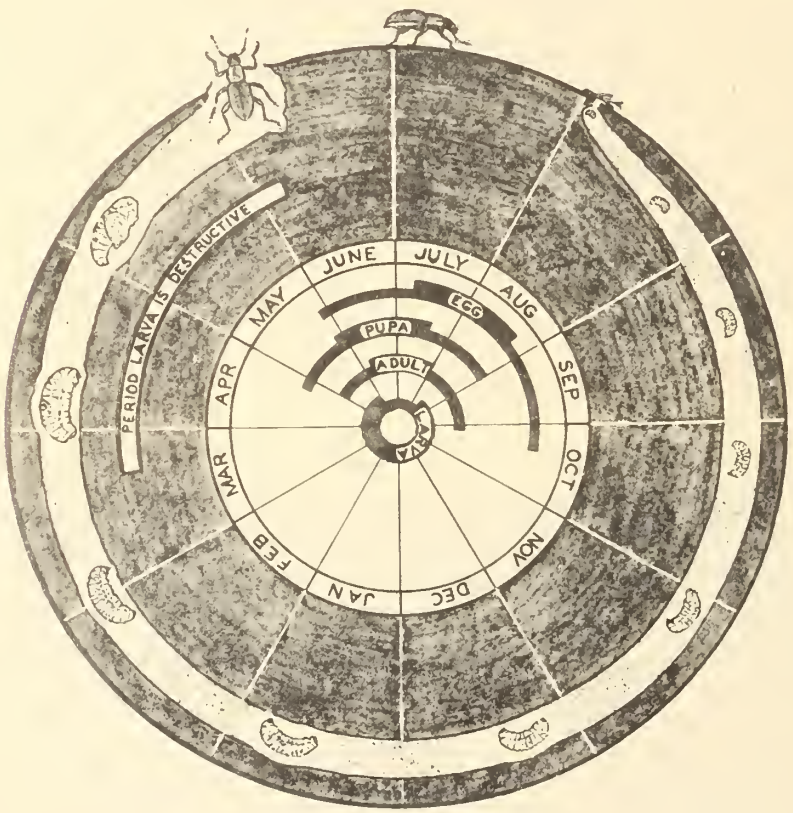

Figure 7.--Life cycle of the white-fringed beetle.

GEOGRAPHICAL DISTRIBUTION

White-fringed beetles occur in Argentina, Chile, Uruguay, and Brazil. In Chile their range is almost continuous from the irrigated district of La Serena in the north to the vicinity of Angol in the south. In Argentina they are found from Jujuy and Santiago del Estero, and possibly farther north, to the provinces of San Juan, La Pampa, and Rio Negro in the south. The beetles are generally distributed over Uruguay and are found in limited numbers in Brazil in the state of Rio Grande do Sul. They have also been identified from New South Wales, Australia, where they probably are not native.

White-fringed beetles were probably introduced into the United States at one or more ports in shipments from the South American continent. After their discovery in Alabama and Florida in 1936, scouting inspections in 1937 at ports of entry and along railroad rights-of-way and other arteries of transportation revealed the presence of these insects in Louisiana and Mississippi. In 1942 they were found in North Carolina, at Wilmington, in the course of regular scouting activities. In 1946 infestations of white-fringed beetles were discovered in Georgia near Eastman, Fort Valley, and Macon. The Georgia infestations were found not only on general cropland and on residential and industrial sites, but also in large ornamental nurseries. Inspection of properties landscaped with ornamentals obtained from these nurseries disclosed many additional infestations in Georgia, one in South Carolina, and two in Alabama. The finding of widespread infestations in nurseries and ornamental plantings introduced a new approach to the technique of survey procedures--namely, tracing the movement of articles capable of disseminating the insect which were shipped from newly discovered infested properties and thereby possibly locating additional infestations. In 1948 white-fringed beetles were found in Tennessee, in the city of Memphis. Since Graphognathus leucoloma fecundus was discovered in this country, other species and races of Graphognathus have been found which are also economically important and are distributed as follows (fig. 8):

leucoloma dubius (Buch.)
- Alabama
- Florida
- Mississippi
- North Carolina

leucoloma fecundus Buch.:
- Alabama
- Florida
- Louisiana
- Mississippi

leucoloma imitator Buch.:
- North Carolina

leucoloma pilosus (Buch.):
- Alabama

leucoloma striatus (Buch.):
- Alabama
- Florida
- Georgia
- Louisiana
- Mississippi
- South Carolina
- Tennessee

peregrinus (Buch.):
- Alabama
- Florida
- Louisiana
- Mississippi

minor (Buch.):
- Florida

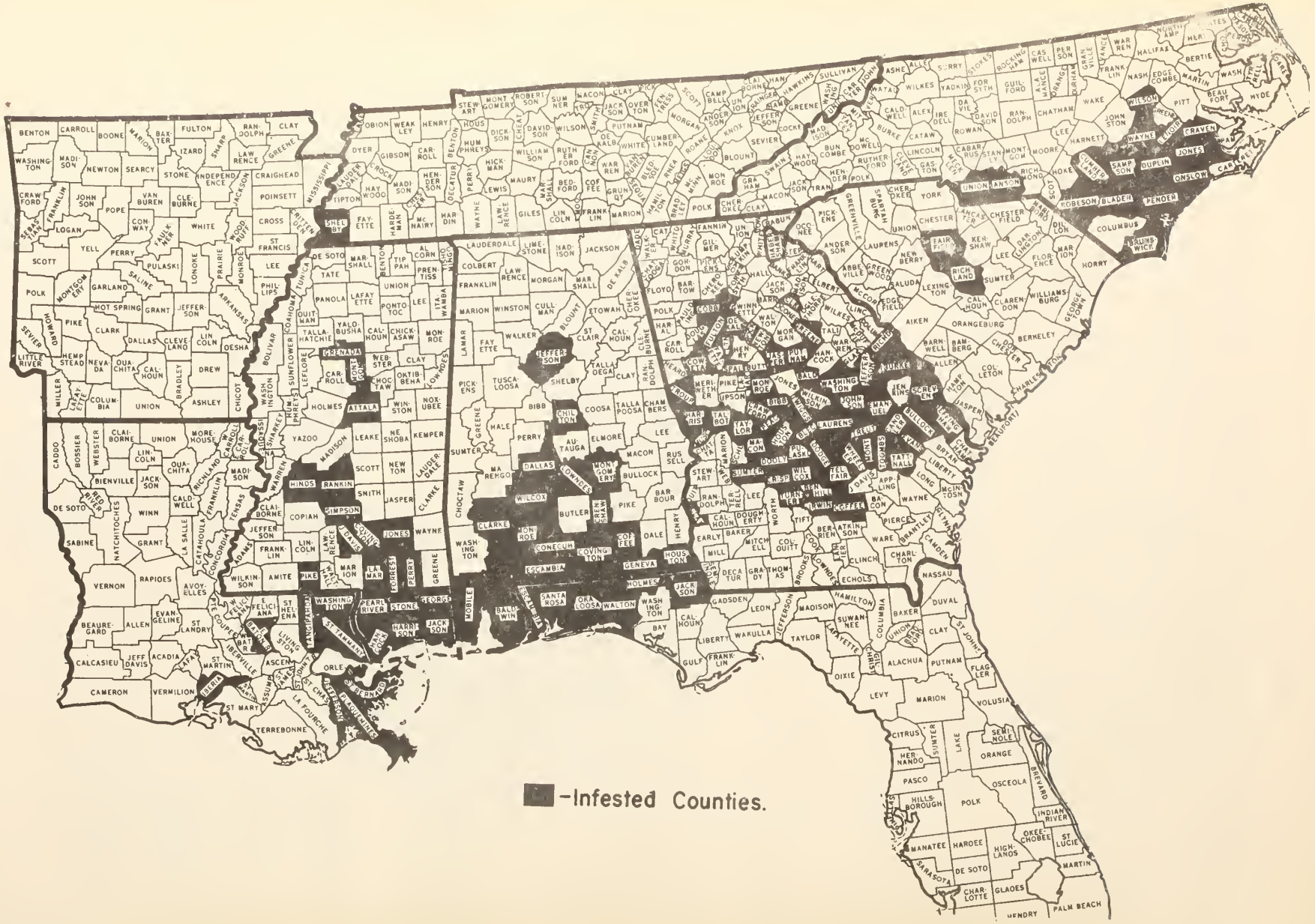

Figure 8.--Distribution of white-fringed beetles in the United States.

Figure 9.--Distribution of the white-fringed beetle in South America.

Figure 10.--Probable areas in North America adaptable to white-fringed beetle development.

In surveys conducted since 1937, approximately 248,000 acres in these States have been found to be infested.

The potential range in the United States was estimated by studying geographic and climatic data collected from South America, the native home of white-fringed beetles, in relation to the known distribution on that Continent. The known southern limit of the beetles in South America is south latitude 40 degrees (fig. 9). In the Northern Hemisphere this corresponds to the latitude of Philadelphia, Pa. (fig. 10). The northern limit, south latitude 23 to 29 degrees, corresponds in the Northern Hemisphere to a broad line running through the tip of the Florida peninsula. The temperature for the northern limit of distribution in South America corresponds approximately to the 70° F. isotherm. In North America this isotherm runs along the Gulf Coast. The southern limit in Argentina corresponds to the 57° F. isotherm. In the United States this mean annual temperature is approximately that of Washington, D. C.

This evidence indicates that the infested areas along the Gulf Coast are probably the southernmost to which the beetles might adapt themselves in North America. Northward they might extend to the latitude of Washington, D. C. However, mean annual temperature and latitude ranges may not be the only factors that influence their distribution. Soil type, soil temperature during the winter, and land usage may also be important. Rainfall is probably secondary, as the precipitation ranges from less than 20 inches to more than 100 inches per year in different parts of Chile known to be inhabited by these beetles.

QUARANTINES AND SUPPORTING MEASURES FOR PREVENTING SPREAD OF BEETLES

Quarantine regulations against white-fringed beetles were promulgated by the Federal Government and the various States involved soon after the discovery of this pest. State plant quarantines were initiated for restricting intrastate movement from infested areas of materials believed capable of spreading the insects. A Federal domestic plant quarantine was also promulgated, effective January 15, 1939, to restrict the interstate movement of articles believed capable of disseminating the beetles.

These early quarantines were prohibitive rather than restrictive in nature, as information was meager on the biology and habits of these insects. The quarantines were revised from time to time with the accumulation of additional information about the beetles and their susceptibility to insecticidal and fumigation treatments.

Although the beetles do not fly, prevention of spread is made exceedingly difficult by the cosmopolitan feeding habits of the insects, their close association with roots and soil, the tendency of the adults to conceal themselves when disturbed, the wide range of carrier materials, the volume of movement from large areas throughout the year, and the numerous channels of possible spread. When it is considered also that any individual egg, larva, pupa, or adult can start an infestation in a new

locality, it is seen that only by stringent quarantine measures aided by a drastic program of population suppression at shipment or movement sources can we hope to be successful in preventing dissemination.

Quarantine procedures are not the only safeguards for preventing the spread of infestation. The insects may inadvertently be disseminated by the ordinary movements of man from public gathering places such as schools, shipping points, processing plants, and railroad yards. The adult beetles may crawl into vehicles located in such areas and be distributed by these means. Therefore, in addition to quarantine procedures, insecticides are applied around such places to reduce populations and minimize the danger of spread.

Transportation of soil is one of the most likely means of disseminating white-fringed beetles. The insects spend the greater portion of the year in the soil as larvae; eggs, pupae, and teneral adults may also be found in the soil at certain seasons of the year. The movement of nursery stock and other plants with soil is especially dangerous, because the larvae are usually found close to the roots. As a basis for certification bare-rooting is resorted to, especially in those plant species having matted root systems. Larvae may be completely removed by thorough washing of these roots, or destroyed in soil balls up to 16 inches in diameter by fumigation with approved dosages of methyl bromide.

DDT broadcast at the rate of 50 pounds per acre as a dust or as a suspension spray and immediately worked into the soil by disking or cultivation will eliminate white-fringed beetles. A treatment of this type may be applied in nurseries, and plants grown in soil so treated are eligible for certification without further treatment. However, since a few large larvae which are difficult to kill with DDT may carry over to the next year, the nursery stock may not be certified until after two adult-emergence seasons. The single 50-pound soil treatment is supplemented during the first season with multiple spray applications at one-half pound of DDT per acre. Potted plants grown in sterilized soil containing DDT at the rate of 1 ounce per cubic yard are also eligible for certification.

The larvae are also likely to be transported in uncured bulbs, tubers, and corms of ornamental plants unless properly treated. The movement of peanuts and peanut hay from infested areas is especially dangerous, as this preferred food plant of the adult beetle is conducive to heavy oviposition, and eggs are often deposited on the stems which are in contact with the soil.

SURVEYS

One of the principal activities of the white-fringed beetle control project is to conduct surveys for locating new infested areas and delimiting known infestations. These surveys are important adjuncts to both quarantine and control activities, as the information gained therefrom is used to determine boundaries when establishing quarantine areas and to ascertain the need for applying insecticidal treatments to infested properties. Because of the importance of these surveys, considerable attention has been devoted to developing methods of inspection for both larval and adult white-fringed beetles.

Inspection for Larvae

Inspections for larvae of white-fringed beetles are conducted early in the spring, when vegetation is young and most susceptible to injury by the root-feeding larvae. Discovery of a new infestation early in the larval season not only serves as a basis for the immediate promulgation of quarantine action, but also permits the inception of a control program during the life of the beetle generation then present.

White-fringed beetle larvae are known to feed upon 385 species of plants distributed in 41 orders. Since it would be impossible for personnel not thoroughly trained in taxonomic botany to become familiar with all these plant species, and since inspection for larvae under so many plants would be slow, tedious, and costly, a standard method of larval inspection was established which has proved satisfactory. In the system of survey thus devised five beetle relationships are taken into consideration: (1) Likely areas, (2) favorable sites, (3) preferred plants, (4) selective sampling, and (5) plant symptoms.

Likely areas.--From the points of introduction into the United States white-fringed beetles spread along the various arteries of transportation and became established in other areas. Since railroads undoubtedly played an important part in the early dissemination of the pest in this country, railroad yards and industrial and processing plants were of major interest in early inspection programs. The application of control measures and the judicious enforcement of quarantines have minimized railroads as a source of spread, and the larger infestations which were established by such movement before the control project was begun have probably been located by search along transportation lines. From a survey standpoint, therefore, railroad yards, processing plants, and community centers are now of less importance. Of primary importance at the present time are locations to which materials capable of disseminating infestations were moved from known sources of infestation prior to their discovery. First consideration is accorded properties that have been landscaped with nursery stock moved from areas of known infestation. In fields displaying loss of stand characteristic of white-fringed beetle injury inspectors look for larvae in the soil around the roots of dead, dying, and dwarfed plants. This approach may be considered as the first step in surveying regions not known to be infested.

Favorable sites.--White-fringed beetle larvae occur more frequently in certain ecological environments than in others. Most of the species and races are seldom found in woods, swamps, or old-stand native vegetation. When present in numbers, they usually occur on land that is well drained and has recently been disturbed by cultivation or other human activities. On farm land the inspector concentrates on cultivated fields, pastures, and fence rows, rather than woody swampland. White-fringed beetles are seldom found in well-kept lawns and, if present, occur in such limited numbers that detection is difficult. Therefore, in residential areas the inspector limits his search to flower beds and shrubbery.

He also inspects undeveloped lots and alleyways in the vicinity. Since the amount of time that he can spend in any one area is limited, the inspector gives special attention to the most favorable beetle sites.

Preferred plants.--Although white-fringed beetles are known to feed on several hundred species of plants, observations over a period of years have disclosed that certain ones are preferred by the larvae. That is, in random diggings under many different plants in an infested field, larvae are found more frequently under one plant species than under another. In a heavily infested field, of course, larvae may be present under practically every species of plant. Inspectors are thus instructed to use selective diggings and to specialize on certain plants in preference to others. These preferred food plants include practically all field and garden crops and native vegetation such as dogfennel, Polypremum, evening-primrose, goldenrod, ragweed, broomsedge, wild geranium, plantain, wild lettuce, dock, Euthamia, sheepsorrel, and various briers. Broomsedge and other perennials, such as dogfennel, which are favored by the adult beetle as shelter plants, are carefully inspected, especially during the early spring, as the adult often oviposits at the base of these plants and larvae may be concentrated there.

Selective sampling.--After an area has been geographically and ecologically delimited, the acreage is still too large for digging every preferred food plant that may be found thereon. A selective sampling is therefore made, in which preferred food plants are inspected in representative portions of the land. Inspection of a field, for example, might include examination of the soil under preferred food plants growing in the shade of trees, in the direct sun, in the interior of the field, and at its periphery. This method has been found more satisfactory than sampling by digging under the preferred food plants every few feet apart.

Plant symptoms.--When young plants are attacked by larvae, they may show certain abnormal symptoms, such as wilting, reddening, and yellowing. If all plant species thus attacked displayed symptoms quite distinct from those caused by other factors, inspection for larvae would be greatly simplified. However, the morbid plant symptoms usually associated with the larval activity of white-fringed beetles are identical with those caused by several other agents. Furthermore, these symptoms, when caused by white-fringed beetles, are sometimes displayed only by low-growing or very young plants in the early spring and in heavily infested areas, and they tend to disappear in those plants that survive. Thus, the search for morbid plant symptoms cannot be considered a continuously valid method of larval inspection by itself. However, in most areas it is useful during the early spring in limiting still further the number of plants to be examined after the previously mentioned approaches have been used.

In looking for larvae the inspector digs the plant up by the roots with a hand trowel or a shovel, and breaks the soil apart. It is not necessary to dig much dirt, as the larvae, if present, will be found on the roots or nearby in the soil.

Figure 11.--Characteristic white-fringed beetle larval damage to Irish potatoes.

Figure 12.--White-fringed beetle adult in characteristic feeding position on peanut leaf.

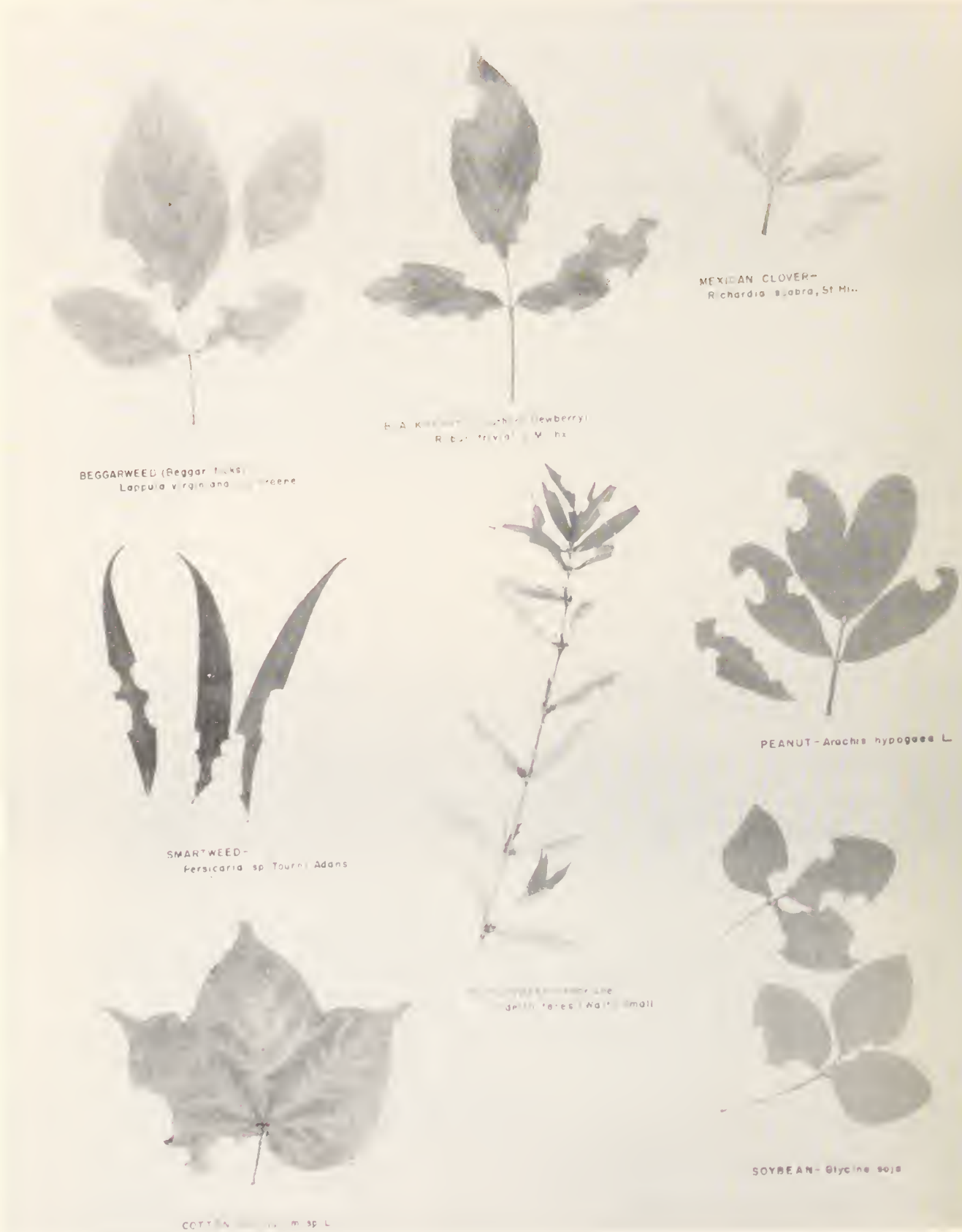

Figure 13.--Feeding signs of white-fringed beetle adults.

Inspection for Adults

When inspection for adults is employed for locating or delimiting infested areas, the various approaches described above under inspection for larvae are also used. In addition, advantage is taken of two primary instincts of the beetle, viz., its search for food and its urge for shelter. After he has found a suitable environment, the inspector looks for preferred food plants showing characteristic feeding signs. The adult beetle straddles the leaf margin, extends its head as far as possible, and cuts the leaf edge. Then it draws the head downward, removing and ingesting a marginal section of leaf tissue. When the head has completed the maximum arc, it is again thrust forward, and another narrow strip is cut and eaten in the same way. Individual feeding varies considerably, but beetles not disturbed seem to eat away three or four such marginal strips without changing position. The leaf area thus removed is approximately one-quarter of an inch in length along the leaf margin and about three-sixteenths of an inch deep. Such cuts are typical feeding signs, but individual feedings may overlap, and a typical sign may be altered or enlarged by additional feedings until the entire leaf from the margin inward may be consumed. Figure 12 shows the insect in characteristic feeding position. Typical feeding signs on a number of preferred food plants are shown in figures 13 and 14.

Although these feeding signs are characteristic for white-fringed beetles, they cannot readily be distinguished from those of some other insects. However, these signs may be helpful to the inspector when used in conjunction with preferred food plants occurring in a favorable environment. When feeding is recent, the edge of the incised area will be green or show only a slight discoloration, and the beetles may be found attached to the plant or on the ground close by. Old feeding signs show a marked discoloration along the periphery of the leaf. Since the beetles spend part of the day under preferred food or shelter plants, a search is made on or beneath these favored plants whether or not feeding signs are noted. When disturbed the insects will often drop from the plants and feign death, so that they are difficult to detect. Field experience is an important asset to an inspector looking for adults, as a knowledge of the insect's habits, reactions, and environmental preferences is of much value in this type of activity.

From a project standpoint, inspection for larvae is more profitable than inspection for adults. The latter type of inspection is possible only during a relatively short period of the year, when control activities directed against adults are underway. Personnel of the project are more efficiently utilized in inspections for larvae during the spring and early summer before such control operations begin. During the control season inspection for adults may be carried on between control operations as a supplement to inspection for larvae.

CONTROL

When white-fringed beetles were first discovered in this country, little information was available on which to base a control program. Various emergency measures were attempted but abandoned as being outdated or impracticable. They included the use of barrier ditches, trap crops, and flame throwers. As research data on the beetles were accumulated, other methods of control proved to be more successful, and operations against the pest were revised accordingly. Herbicidal sprays, fallowing, and clean cultivation were found to reduce populations, but such treatments have been superseded by the use of insecticides, which give comparable results at less expense.

All control work has been undertaken as a cooperative State and Federal function to prevent or retard further spread of the beetle and to protect crops in the infested area against loss.

Herbicides

A sodium arsenite-fuel oil herbicide is used to a limited extent around important dissemination points, such as sales and shipping areas and railway sidetracks, where the hazard of spread is so great that even light populations are dangerous. The herbicide eliminates those species of broad-leaved plants offering food and shelter to the insects and forces them to other environments. During this movement populations are drastically reduced by exposure, and the beetles are also killed by contact with the herbicide or from eating foliage sprayed with this poison. The continued use of the arsenical herbicide results in a predominantly grassy condition not conducive to large white-fringed beetle populations.

The employment of herbicides in recent years has been limited because of their high cost, their toxicity to livestock, changes in flora in many previously treated areas, and low beetle populations now existing in environments adapted to such treatment. Its use in the future will probably be confined largely to railroad yards and sidings and to isolated locations where the insects cannot be controlled by other methods.

Insecticides

The use of insecticides has become the most important method of controlling white-fringed beetles, because of the vast acreage that may be effectively treated at comparatively low cost. Moreover, the production of crops is not interrupted as when clean cultivation and fallowing are practiced.

Calcium arsenate was the first insecticide employed against white-fringed beetles; it was used to a limited extent as a dust in 1938. Since this chemical causes burning of leguminous plants such as peanuts and velvetbeans and is extremely toxic to livestock, it was replaced largely by cryolite in 1939. The use of cryolite made control operations possible on every type of infested property, as this insecticide is not injurious to most plant life and is relatively nontoxic to livestock.

Figure 14.--Feeding signs of white-fringed beetle adults.

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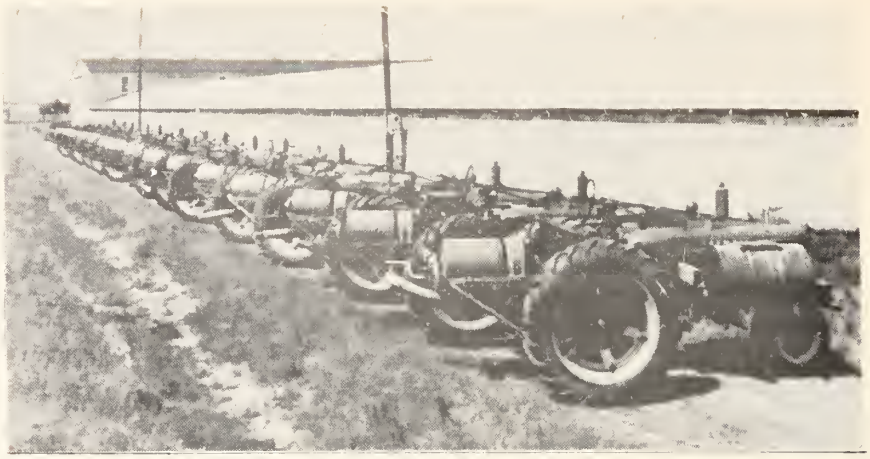

Figure 15.--Fleet of machines for applying concentrated sprays from the ground.

Figure 16.--Concentrated-spray machine in operation.

Figure 17.--Airplane with special spray boom for applying concentrated sprays for control of white-fringed beetles.

The insecticides were originally applied as dusts, but because of frequent rains during the control season they were superseded by sprays, which are more adhesive. Dilute sprays were first employed, but concentrated sprays have been developed which are more adhesive and can be applied more economically. Special machines for applying the concentrated sprays have been devised, which are now used extensively in all control areas (figs. 15 and 16). The airplane has also been used successfully for applying concentrated sprays, and a spray boom has been devised for this purpose (fig. 17).

Control procedures were greatly modified with the advent of DDT. High mortalities of adults were obtained with calcium arsenate and cryolite sprays (or dusts under favorable weather conditions), but subsequent populations of larvae were not correspondingly reduced. It is necessary to obtain very high mortality of adults to affect future populations of larvae, as the white-fringed beetle has a high reproductive potential. DDT is toxic to larvae as well as adults, and drastically reduces populations of larvae and holds them at low levels. Its use against white-fringed beetles shows much promise, and many field studies have been undertaken to find the most effective methods of applying it. Although this work is still in progress, much information has been obtained which is being used in large-scale operations against the beetle.

Methods of Applying DDT

DDT may be used in white-fringed beetle control as a soil treatment or as a foliage application. As a soil treatment, or control for larvae, the DDT is applied to the ground surface as a dust or spray and then incorporated into the soil by cultivating. As a foliage treatment, or control for adults, the insecticide is applied to the foliage and ground as a spray and is not subsequently worked into the soil.

Treatment of soil for control of larvae.--DDT is most effective when applied as a soil treatment against the larvae. This is also an economical method of treatment, since single 10-pound applications have remained effective for the 5-year duration of tests still in progress. Moreover, this type of treatment may be applied at a time of year when crops are not grown, and when it will not interfere with farming practices. When applied in the fall or early spring at the time of plowing or disking, the DDT may be incorporated into the soil with farm equipment in the course of regular farming operations.

DDT soil treatments are applied as suspensions or dusts, at the rate of 10 pounds of DDT per acre. The suspensions are applied as concentrated sprays by machine. They are prepared by mixing a wettable powder containing 50 percent of DDT directly with water. The dusts are applied by hand, or with a fertilizer distributor, such as one attached to a standard grain drill. They are prepared by mixing the 50-percent DDT with inert carriers to concentrations of 2.5 to 5 percent of DDT. Dusts have been somewhat more effective than suspensions as soil treatments. In any case thorough incorporation of the DDT into the soil immediately after treatment is essential for satisfactory control.

Broadcast dust treatments of 5 pounds of DDT per acre reduce larval populations to a point where economic damage to most crops would not be expected for one year, but do not last long enough to protect subsequent crops. Ten pounds of DDT per acre applied in this manner almost completely eliminates larval populations and is just about as effective as heavier applications. Therefore, the 10-pound dosage is used for general treatment.

DDT applied broadcast as a dust in the fall and immediately disked into the soil is the most effective treatment yet found for control of white-fringed beetles. Most of the larvae are small at this time of the year, and are close to the surface, where they are likely to come in contact with the insecticide. Moreover, small larvae are more susceptible than large larvae to DDT. However, if fall plowing is not practiced, a DDT soil treatment at the time of breaking the land in the spring is preferable to a fall surface treatment with the DDT not incorporated into the soil until the following spring.

Ten pounds of DDT broadcast and worked into the soil is much superior to application in the rows, in the over-all reduction of larval populations. However, DDT applied in the row at the time of spring planting might give better protection of the immediate crop, as the insecticide would be concentrated in the plant-root area.

Treatment of foliage for control of adults.--Although soil treatments with DDT are highly effective in controlling larvae, it is evident that not all infested properties can be treated in this manner. There are vast acreages of permanent pasture, railroad rights-of-way, and industrial properties which are infested with white-fringed beetles and constitute a hazard of spreading the beetle to uninfested areas. On these lands the control of adults is necessary, and this can be accomplished best by foliage applications at the rate of 1/2 to 1 pound of DDT per acre at 2- to 3-week intervals throughout the adult-beetle emergence season. When immediate mortalities are desired to reduce the danger of spreading the beetle, a foliage rather than a soil treatment must be applied. DDT worked into the soil at the time of application results in a surface concentration of the insecticide which is insufficient for killing adult beetles, and the entire effect of such treatment is that of a larvicide. In surface applications provisions must be made for safety to livestock.

As a foliage treatment DDT may be applied (1) in a suspension, by mixing DDT dust containing a wetting agent with water (or adding the wetting agent); (2) in an emulsion, by dissolving technical DDT in a suitable solvent, adding an emulsifier, and mixing with water; (3) in a solution prepared by dissolving technical DDT in an auxiliary solvent (as xylene) and further diluting with a cheaper and less soluble solvent (as kerosene), or dissolving the DDT in a larger quantity of the regular solvent without the auxiliary solvent; (4) in a dust diluted with an inert carrier. Methods (1), (2), and (4) have also been used in soil treatments against white-fringed beetle larvae.

DDT emulsions and suspensions applied to the foilage during the emergence season have been very satisfactory against white-fringed beetle adults. When applied as a dust or as a dilute or concentrated

spray to foliage on idle or semicultivated land in several one-third pound per acre applications, DDT has been appreciably more effective against adults of Graphognathus leucoloma fecundus than a similar number of applications of cryolite or calcium arsenate at 12 pounds per acre. It has also been as effective as these insecticides against G. peregrinus. The reductions from such foliage treatments are the result of killing the adults and possibly newly hatched larvae as they enter the soil, rather than of any residual action of the DDT against the larvae in the soil.

In a number of field tests single applications of 5 to 10 pounds of DDT per acre to the foliage on idle or semicultivated land during the adult emergence season were unsatisfactory in reducing subsequent larval populations. When 5 pounds of DDT per acre or less was applied to the foliage in a season, this amount had to be divided into at least five applications in order to achieve satisfactory larval reduction. In general, the larval reduction from a given amount of DDT increased with the number of applications.

Emulsion sprays gave higher mortalities of adult beetles than suspensions when applied as single foliage treatments at 5 or 10 pounds of DDT per acre. The superior results were probably due to the greater adhesiveness of the emulsion, which allows the DDT residue to remain longer on the surface of the foliage and soil. Multiple 1-pound-per-acre applications of emulsion were also superior to an identical number of suspension treatments. Emulsion sprays applied as a surface treatment on idle land in the fall of the year at rates up to 12 pounds of DDT per acre showed no effect on adults emerging the following summer, an indication that the DDT showed no residual action on the surface from one year to the next.

Effect of DDT on Crops

Tests conducted to determine the effect of DDT as soil and foliage treatments at the dosages given above showed that no adverse effects on the foliage or yield were to be expected from white-fringed beetle control operations with DDT on crops commonly grown in the areas of infestation. Emulsion sprays applied at the rates of 5 and 10 pounds of DDT per acre (with 5 and 10 quarts of xylol, respectively) in 6-1/2 gallons of spray liquid had no adverse effect on the foliage of butter beans, snap beans, cabbage, sugarcane, corn, cotton, cucumber, lettuce, English peas, field peas, tomatoes, and turnips. Records taken on snap beans and tomatoes indicated no loss in yield. An emulsion applied at 5 pounds per acre to a large number of ornamental plants had no detrimental effect on the foliage.

DDT suspensions applied as soil treatments at rates up to 100 pounds of DDT per acre had no adverse effect on the yield of blue lupine, cabbage, Austrian winter peas, turnips, vetch, and greens. Emulsions and suspensions applied as soil treatments at rates of 5 and 10 pounds of

DDT per acre had no effect on the yield of snap beans, corn, sweet-potatoes, peanuts, or tomatoes.

In control operations against the white-fringed beetle DDT is not applied to crops where the foliage or other exposed portions of the plant are consumed by man or animals, because of the hazard involved. Studies have indicated that an appreciable quantity of this insecticide is stored in the fatty tissues of animals that have fed on treated foliage, and is also found in the milk, where it was concentrated in the butterfat.

Fumigants

Fumigation is very effective in killing white-fringed beetle larvae and pupae in the soil. However, the cost of such treatment is comparatively high, and its use is confined to small, isolated infestations. Portions of some nurseries have been fumigated with methyl bromide when the cost to the owners was not prohibitive.

Biological Control

Extensive search was made in South America by the Division of Foreign Parasite Introduction for natural enemies of white-fringed beetles in their native habitat. In Argentina, Uruguay, Chile, and Brazil several thousand Graphognathus leucoloma larvae and adults were examined for the presence of parasites, with entirely negative results. In addition, large numbers of egg masses were exposed in infested fields, and none were found to be parasitized. These studies indicated that parasites do not exert any appreciable control on white-fringed beetles in South America.

Observations over a period of years in the infested portions of the United States made by the Division of Cereal and Forage Insect Investigations, in which thousands of eggs, larvae, pupae, and adults were examined, failed to disclose the presence of any insect parasites. Tachinid eggs were found on a few adults of four species of white-fringed beetles, but in none was successful parasitism reported. Thousands of eggs have been exposed in infested fields, but no egg parasites have been discovered.

Parasitic nematodes of the genus Neoaplectana were found to attack white-fringed beetle larvae throughout their known range in the United States. These parasites proved to be a controlling factor in certain isolated localities in Harrison County, Miss., but were not of economic importance elsewhere. These nematodes seem to be more numerous in undisturbed land than in cultivated fields or other areas disturbed by man-made enterprises. Thus, with few exceptions, the parasite does not build up sufficient populations in the ecological enviroment most suitable for white-fringed beetle development. Other species of parasitic nematodes have been found that attack the larvae on occasion, but none were of any practical consequence.

The fungus Metarrhizium anisopliae sometimes attacks white-fringed beetle larvae in the field, but has not proved to be of economic importance.

Numerous predators have been found in the act of destroying white-fringed beetle adults in the field, but predation is not thought to be an important factor in controlling beetle populations. Predators observed attacking these insects included certain insects, spiders, amphibians, reptiles, birds, and mammals.

Cultural Control

Although the main efforts have been directed towards preventing further spread of the beetle by applying the necessary regulatory procedures and suppressing populations with insecticides, a cultural control program is also in operation. Farmers on infested acreages are encouraged to adopt certain cultural practices in order that they may conduct their business profitably in the presence of the insect.

Since the economic importance of white-fringed beetles is due to the damage done by the larvae in the spring of the year, the timing of crop planting is an important factor influencing subsequent plant injury. The planting of suitable crops is also of importance, since the fecundity of the adult varies tremendously with the types of food plants consumed.

During the summer months larval populations are negligible, and during the fall and early winter larvae may be numerous but are usually too small to cause appreciable economic damage.

Legumes are favorable food plants for both larvae and adults, and induce heavy oviposition by the beetles that feed on them. Wherever possible, farmers on land with high beetle populations are encouraged to grow fibrous-rooted plants, such as oats and other small grains, instead of corn intercropped with velvetbeans. They are also urged to grow the necessary soil-building legumes, such as lupines and Austrian winter peas, in the winter. The oats and winter legumes may be planted in September and October and therefore escape injury by the larvae. Furthermore, because of their more extensive root systems, crops planted in the fall can withstand attack by the larvae the following spring better than can spring-planted crops.

Other recommended practices include the solid planting of corn rather than intercropping with legumes; the planting of summer legumes such as peanuts, velvetbeans, or other primary food plants of the insect on not more than one-fourth of the cropped land; and the production of these leguminous crops not more than once in three or four years on the same land. Permanent pastures are also recommended.

Studies have shown that different soil types in the same area have varying beetle populations even though identical crops are planted thereon. Therefore,in an over-all cultural control program farmers are encouraged to plant their necessary cash crops, which may be conducive to high beetle populations, on the portions of their land that by observation seem to be least favorable to build-up of beetle populations.

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